VA-3499-009-02-TR

Matched Filter Processor for Detection and Discrimination of Unexploded Ordnance: OASIS Montaj Integration

15 November 2002

Contract Number:	**DACA72-02-P-0024, CDRL No.: A007**
ESTCP Project No.:	**199918**

Submitted to:

Department of the Army
U.S. Army Corps of Engineers
Humphrey's Engineer Center Support Activity
7701 Telegraph Road
Alexandria, Virginia 22315
Attention: Mr. Jeff Fairbanks

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **15 NOV 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**

4. TITLE AND SUBTITLE **Matched Filter Processor for Detection and Discrimination of Unexploded Ordnance: OASIS Montaj Integration**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **AETC Inc.,3711 Junction Blvd,Raleigh,NC,67603**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**29**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Contents

Report Documentation Page .... *i*
Table of Contents.. *ii*
1. Introduction 1
1.1 Background 1
1.2 Official DOD Requirements Statement 1
1.2.1 How Requirements Were Addressed 2
1.3 Objectives of the Demonstration 2
1.4 Regulatory Issues 2
1.5 Previous Testing of the Technology 2
2. Technology Description...2
2.1 Overview of the Processor 2
2.2 Filtering Procedure 3
2.3 Peak Finding 4
3. Site/Facility Description...4
3.1 Background 4
3.2 Site/Facility Characteristics 4
4. Demonstration Approach...5
4.1 Performance Objectives 5
5. Performance Assessment 5
5.1 Matched Filter Performance 5
5.1.1 Synthetic Data...5
5.1.2 Jefferson Proving Ground Magnetic Data – Area 1 10
5.2 Data Assessment 23
5.3 Technology Comparisons 23
5.4 Time and Experience Assessment 23
5.5 Technology Transition...23
6. Lessons Learned 25
7. References 26
Appendix A: Points of Contact 27
Matched Filter dynamic link library and Geosoft Executable ....Attached

Matched Filter Processor for Detection and Discrimination of Unexploded Ordnance: OASIS Montaj Integration

AETC, Incorporated

15 November 2002

1. Introduction

1.1 Background

Identifying magnetic signatures that result from unexploded ordnance (UXO) is complicated by the dipolar nature of the signatures themselves and the presence of non-target-generated magnetic fluctuations. Fluctuations in the magnetic field that result from naturally occurring geologic materials, for example, often obscure the signatures from UXO. The presence of metallic debris or shrapnel can also degrade, mask, or complicate analysis.

To improve and automate the analysis of magnetic data, a matched filter autoprocessor was investigated in 2001 under ESTCP funding[1]. The matched filter algorithm, which was originally codified in the Interactive Data Language (IDL; Research Systems, Inc.), implements optimal linear filtering in a threshold-based UXO detection scheme.

The objective of this work was to recode the algorithm such that it seamlessly integrates with OASIS Montaj. OASIS Montaj, developed and marketed commercially by Geosoft, Inc., includes a very large capacity database, a graphical user interface, and a plethora of geophysical processing and mapping routines.

1.2 Official DOD Requirements Statement

The Navy Tri-Service Environmental Quality Research Development Test and Evaluation Strategic Plan specifically addresses, under Thrust Requirements 1.A.1 and 1.A.2, the requirements for improved detection, location and removal of UXO on land and under water. The index numbers associated with these requirements are 1.I.4.e and 1.III.2.f. The requirements are similarly documented in the Army [A(1.1.d), A(1.3.I) and A(1.5.i)] and Air Force [244] statements of need. The priority 1 rankings of these requirements indicate that they address existing statutory requirements, executive orders or significant health and safety issues. Specifically the Tri-Service requirements document states:

> *There are more than twenty million acres of bombing and target ranges under DOD control. Of particular concern for the Navy are the many underwater sites which have yet*

to be characterized. Each year a significant fraction (200,000-500,000 acres) of these spaces are returned to civilian (Private or Commercial) use. All these areas must be surveyed for buried ordnance and other hazardous materials, rendered certified and safe for the intended end use. This is an extremely labor intensive and expensive process, with costs often far exceeding the value of the land… Improved technologies for locating, identifying and marking ordnance items must be developed to address all types of terrain, such as open fields, wooded areas, rugged inaccessible areas, and underwater sites.[2]

1.2.1 How Requirements(s) Were Addressed.

The matched filter processor[1] addressed the requirements for improved detection of UXO, particularly for weak or deep objects in magnetically active or noisy areas. In this work, the detection modules were transitioned into OASIS Montaj, a commercially available, widely distributed, and standard data processing environment for UXO investigations.

1.3 Objectives of the Demonstration

A matched filter processor has been previously developed for automatic detection and characterization of UXO. Details of the processor are fully described in the project's Final Report[1]. The objective of this contract extension was to integrate the algorithm into OASIS Montaj.

1.4 Regulatory Issues

There are no regulatory issues unique to the matched filter algorithm.

1.5 Previous Testing of the Technology

The matched filter routines were prototyped in the Interactive Data Language during ESTCP 199918 [contract DACA-31-99-C-0075]. As detailed in the Final Report, the demonstration was performed on magnetometer data collected during the 2000 UXO Detection/Discrimination Advanced Technology Demonstration at Jefferson Proving Ground Madison, Indiana (henceforth called JPG Technology Demonstration, or JPG TD).

2. Technology Description

2.1 Overview of the OASIS Montaj Matched Filter module

The matched filter processor convolves a dipole-based model signature with a gridded (or krigged) approximation of the measured data. As such, the inputs include the gridded data file, geographic information regarding the site (required in order to calculate the inclination and declination of the Earth's magnetic field), the size of the filter box (described below), and the distance between the sensors and the ground's surface. The outputs include a filtered output grid and an OASIS Montaj database containing the output grid data, spatial locations, and model parameters.

There are three basic steps involved with the matched filter executable. First, the input data are submitted to the filtering routine by calling a Geosoft executable ('matchfilter.gx'). The 'matchfilter.gx' interfaces with the OASIS Montaj database and passes the data to a dynamic link library that creates the filter output grid and model parameters. The second step involves refining the filter output (if desired) by utilizing the model parameters. Third, identifying the peaks in the filter output data creates the anomaly list.

Figure 1 shows the user dialogue window that is displayed upon calling the Geosoft executable ('matchfilter.gx'). Geosoft executables are processes that perform a variety of data processing tasks. Required inputs for the matched filter executable include an OASIS Montaj grid file, the sensor offset (distance between the ground's surface and the magnetic sensors), the base length of the filter box, the latitude and longitude of the site, and geomagnetic reference field information. The 'Output Grid File' requests a filename for the matched filter output results. A database containing all measured data and fit results (or model parameters) is also created using the same name but with a *.gdb extension.

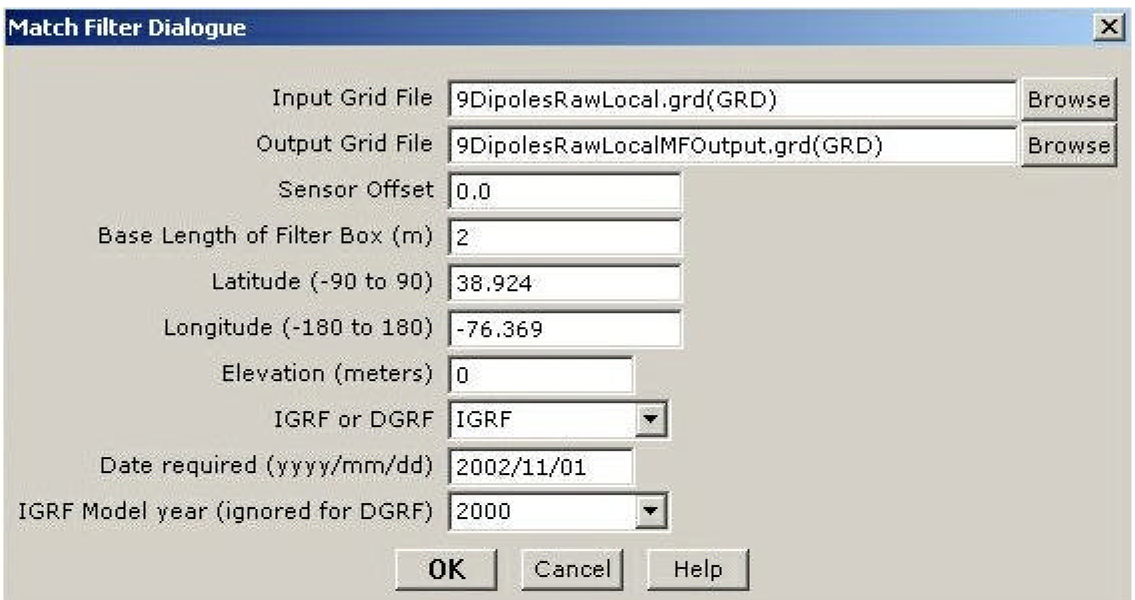

Figure 1. Screen snapshot of the Matched Filter Dialogue box.

2.2 Filtering Procedure

In general, a matched filter operates by convolving the data with an appropriate signal model, accompanied by a search over the unknown parameters in the signal model to maximize the filter output. The matched-filter processor uses a dipole-signal-based model. The filter output at locations of objects that are good approximations to a point dipole and that lie at or near the filter depth are enhanced, while the filter output near objects that are not dipole-like (e.g., geologic features that may have strong signatures in the raw data) or are not compact (e.g., magnetic soil) are suppressed. All compact dipole signatures, even those caused by non-UXO (e.g. metallic clutter or natural magnetic sources), will produce peaks in the filtered data.

The expected dipole signals that are input into the matched filter contain unknown parameters (target orientation, moment, etc.) that must be estimated from the data. This is accomplished by searching over the possible values of these parameters to maximize the filter output.

Similar to the previously prototyped IDL code, a filter box is created around each point (x_0, y_0) in the grid. The model signal in the matched filter is a dipole located at the center of the filter box (x_0, y_0) for various depths, plus a linear magnetic background field. A multiple linear regression on the data for all points in the box yields the best-fit signal model dipole and the background field constants.

The Geosoft version of the matched filter has been modified to search over multiple depths. In the previous IDL version, only a single user-input depth was interrogated. The OASIS Montaj version is hard-coded to search over six depths; namely, 0.25m to 1.5m at 0.25m increments. The depth that produces to the best fit (i.e., lowest error in terms of model minus measured data) is selected, and the model parameters for that depth are stored. An additional modification was made regarding the size of the filter box. In the IDL prototype code, the size of the filter box was a function of the user-selected interrogation depth. It was concluded that the matched filter output was not sensitive to the size of the filter box[1]. In the OASIS Montaj version, the size of the filter box is assigned by the user and is not a function of the interrogation depth.

Additional details regarding the filtering procedures are provided in a previous report[1].

2.3 Peak-finding Procedure

OASIS Montaj supplies an executable (‘gridpeak.gx’) to identify peaks in the matched filter grid.

3.0 Site/Facility Description

3.1 Background

The demonstration of the OASIS Montaj-embedded matched filter was performed in contractor offices on synthetic data and on magnetometer array data previously collected at JPG.

3.2 Site/Facility Characteristics

Three one-hectare sites containing inert UXO, OE scrap, and magnetic soils/rocks were prepared at JPG. As part of the program, the NRL independently surveyed the three sites using the vehicular Multisensor Towed Array Detection System (*MTADS)* magnetometer arrays. These data were preprocessed by the NRL to create geo-referenced mapped data files. The *MTADS* magnetometer data from Area 1 was analyzed using the matched filter routine developed for the OASIS Montaj environment.

4.0 Demonstration Approach

4.1 Performance Objectives

The performance objectives of the matched filter processor are to improve detection and discrimination of UXO, particularly for weak or deep targets in magnetically active or noisy areas. The performance metrics are probability of target detection and probability of false alarms.

Table 1: Performance Criteria

Performance Criteria	**Description**	**Primary or Secondary**
Hazardous Materials	Using magnetometer data, detect UXO in the size range from 20 mm to 155 mm projectiles. Determine the probability of detection.	*primary*
Reliability	Determine the percentage of false alarms.	*primary*

5.0 Performance Assessment

5.1 Matched Filter Performance

5.1.1. Synthetic Data

Synthetic data, created using forward models, were used to evaluate the OASIS Montaj-embedded matched filter routine. Table 2 provides details regarding the location and characteristics of magnetic dipoles while Figure 2 presents a color-coded contoured representation of the synthetic data. The synthetic data contain nine distinct dipoles, each with a unique combination of depth, location, and orientation.

Table 2. Location and Characteristics of Magnetic Dipoles for Synthetic Data

ID	X (m)	Y (m)	Depth (m)	Inc (deg)	Dec (deg)	Size (m)
1	10	10	0.5	0	0	0.05
2	20	10	0.5	0	90	0.05
3	30	10	0.5	0	180	0.05
4	10	20	0.5	30	0	0.05
5	20	20	1.5	30	90	0.10
6	30	20	0.5	30	180	0.05
7	10	30	0.5	60	0	0.05
8	20	30	0.5	60	90	0.05
9	30	30	0.5	60	180	0.05

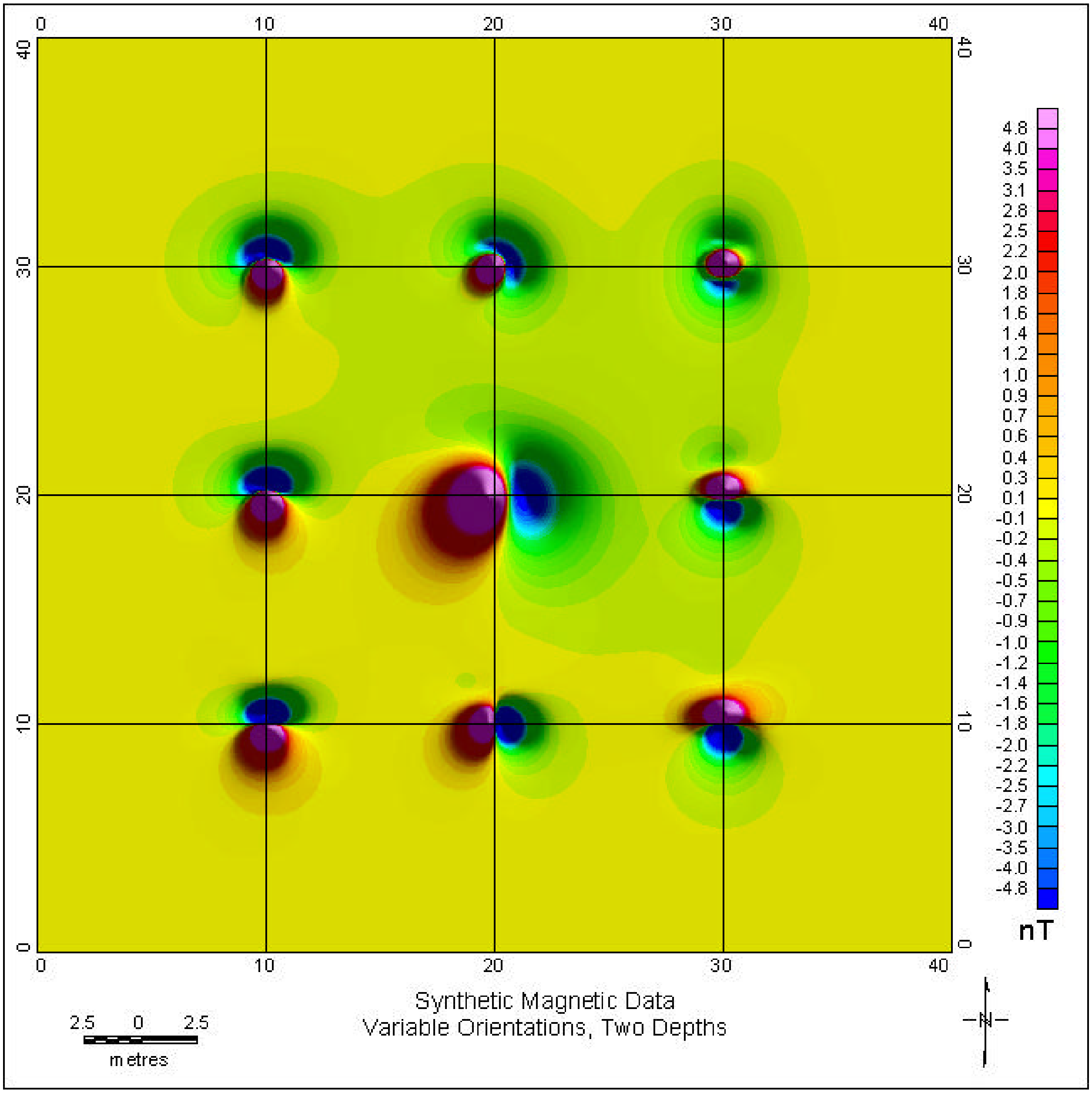

Figure 2. Color-coded map of synthetic data used to test the matched filter routine.

The matched filter output data, shown in Figure 3, clearly indicate the presence of nine dipoles. Processing artifacts are also apparent. The artifacts occur when the filter window contains only a portion of the dipolar signal (typically a single positive or negative lobe) that is associated with the causative source. When this happens, the filter incorrectly creates the missing lobe, which produce erroneous output values. These artifacts were present in the IDL prototyped code as well.

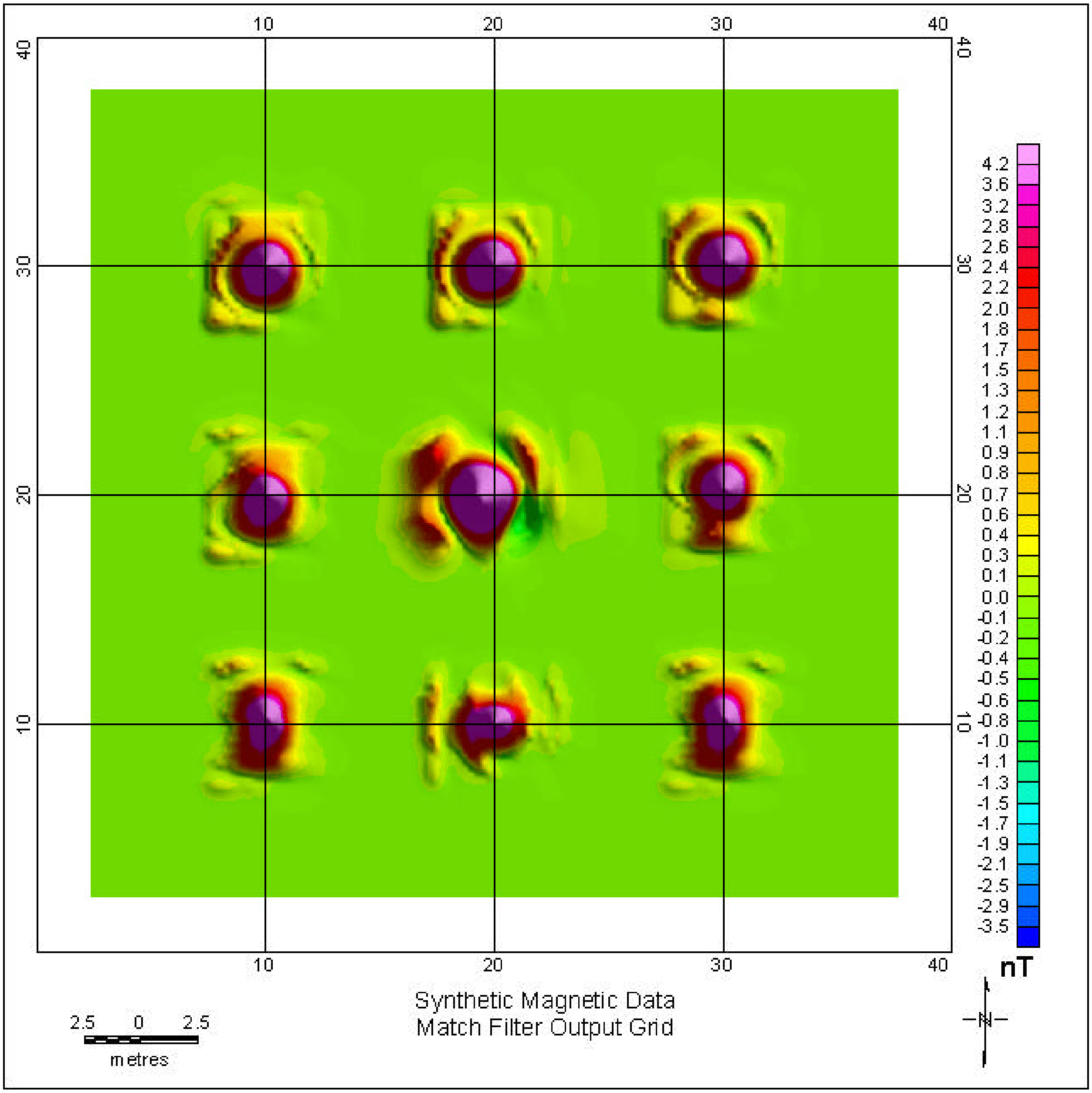

Figure 3. Color-coded map showing results of the Matched Filter.

As briefly mentioned above, the OASIS Montaj matched filter stores the filter results and all derived model parameters in a database. The model parameters can be used to refine the filter

output. Figure 4 shows, in profile form, the matched filter output ('MFoutput'), the model error ('Chisq'), and the ratio ('MFoutput/Chisq'). When the filter window coincides with the center of a dipolar signal, the error term is dramatically reduced. In other words, the derived model closely matches the input (measured or synthetic) data when it is directly on top of the center of the dipole. The horizontal axis in Figure 4 represents the sample number (or fiducial). For reference, fiducial number 12,960 coincides with x=20, y=20 in Figures 2 and 3. There are three major groupings in Figure 4 - each with multiple local peaks. The left-most grouping represents data along y=19.75m. The center grouping represents data along y=20.0 meters, and so on. Within the center grouping (y=20.0 meters), there are three peaks in the MFoutput channel (blue) – each peak represent one of the three dipoles located at x=10-, 20-, and 30-meters.

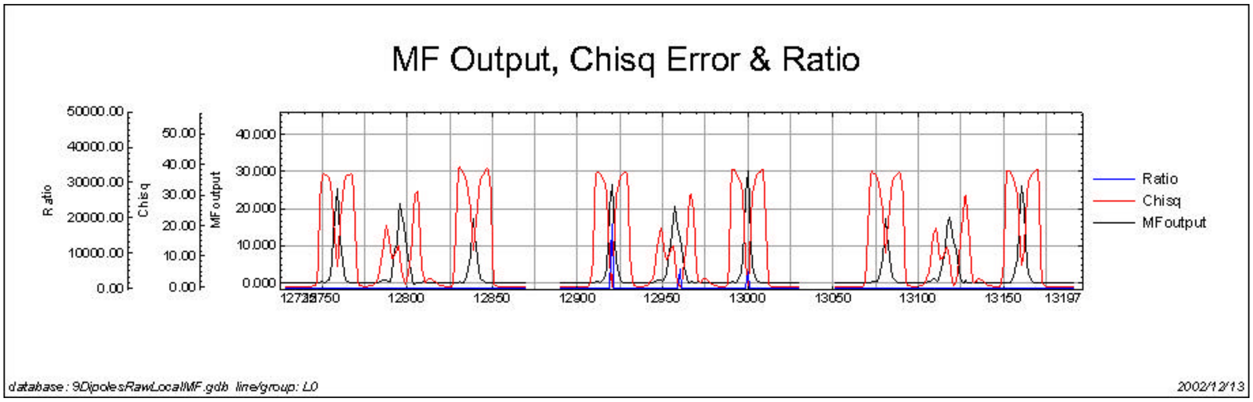

Figure 4. Profile view of the Matched Filter output and Error term. Fiducial number 12,960 corresponds to x=20, y=20 in Figures 2 and 3. Note that the error term ('Chisq') is minimized when the filter output 'MFoutput' is maximized. In other words, when the center of the filter box coincides with a dipole source, the model data closely match the measured (or in this case synthetic) data.

Figure 5 shows the results of dividing the matched filter output by the error term. As observed in the figure, the anomalies possess a very high signal-to-noise ratio and the processing artifacts are reduced.

The derived model parameters for these synthetic data are shown in Table 3. Because the OASIS Montaj version of the matched filter routine includes searches over multiple depths, the anomaly depth estimates are reasonable. Comparing Tables 2 and 3 reveals that the apparent size, depth, inclination, and declination estimates are, in fact, quite good.

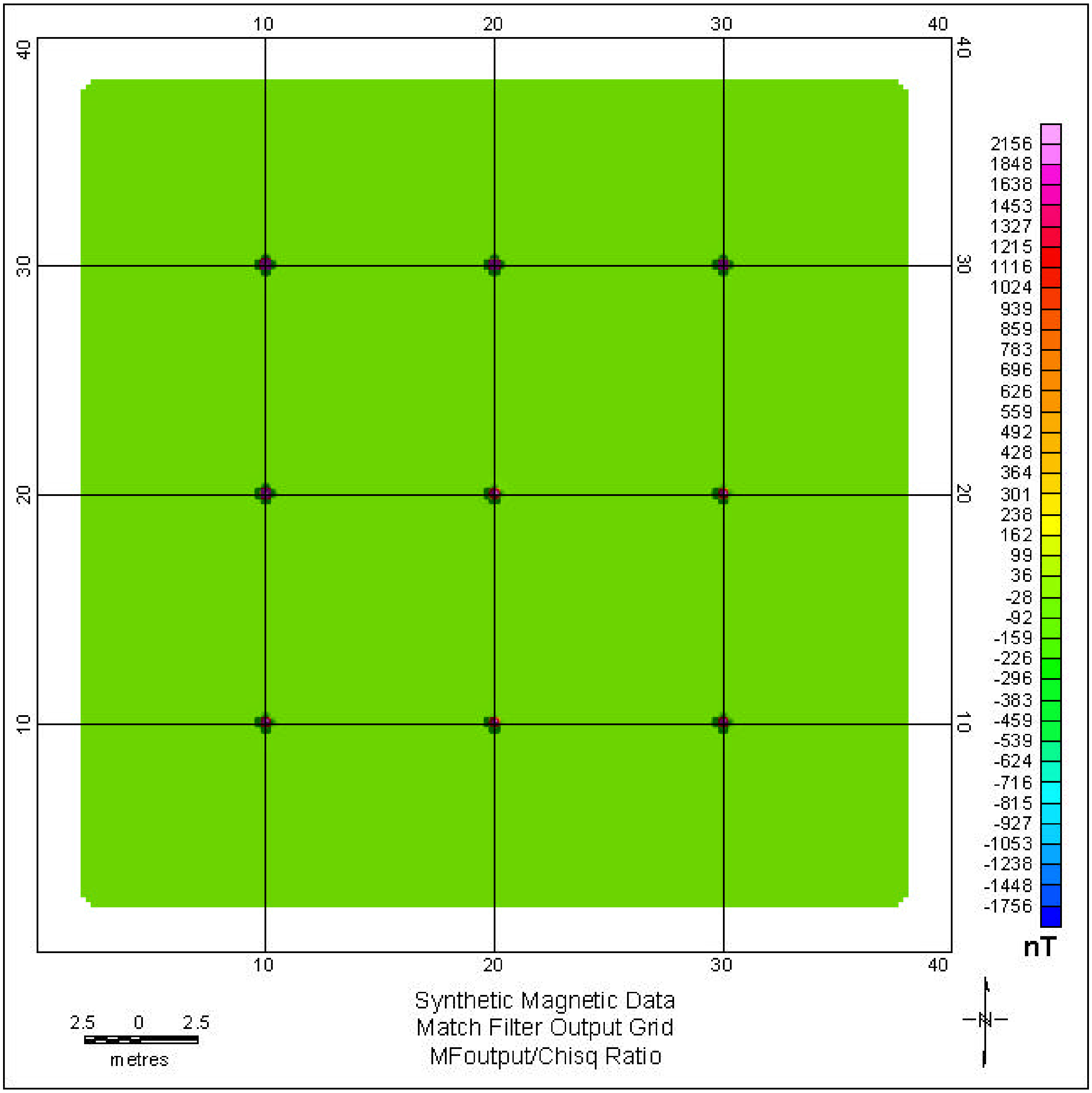

Figure 5. Color-coded map of the matched filter output divided by the error term.

Table 3. Matched Filter Results and Derived Model Parameters

X (m)	Y (m)	Depth (m)	Inc (deg)	Dec (deg)	Size (m)	MFoutput	B0 (nT)	Chisq	Ratio
10	10	0.5	0.5	0.1	0.05	20.8	0.0	0.000	6258
20	10	0.5	-0.3	90.0	0.05	18.9	0.0	0.000	4169
30	10	0.5	-0.5	-180.0	0.05	20.8	0.0	0.000	6202
10	20	0.5	30.7	0.5	0.05	26.4	0.0	0.000	18074
20	20	1.5	29.6	90.6	0.10	12.1	0.0	0.000	5278
30	20	0.5	29.4	179.4	0.05	30.0	-0.2	0.010	4754
10	30	0.5	61.0	1.3	0.05	41.4	0.0	0.000	165120
20	30	0.5	59.3	91.5	0.05	43.1	-0.1	0.000	24330
30	30	0.5	59.2	178.7	0.05	45.1	0.0	0.000	17716

5.1.2. Jefferson Proving Ground Magnetic Data – Area 1

Magnetic data from Area 1, JPG TD, were run through the OASIS Montaj-embedded matched filter to compare with result obtained using the IDL prototyped code. The Naval Research Laboratory acquired the magnetic data using the vehicular *MTADS* platform. Seeded UXO ranged in size from 20-mm aircraft-fired projectiles to 155-mm howitzer projectiles. Figure 6 shows the sensor track density for this site.

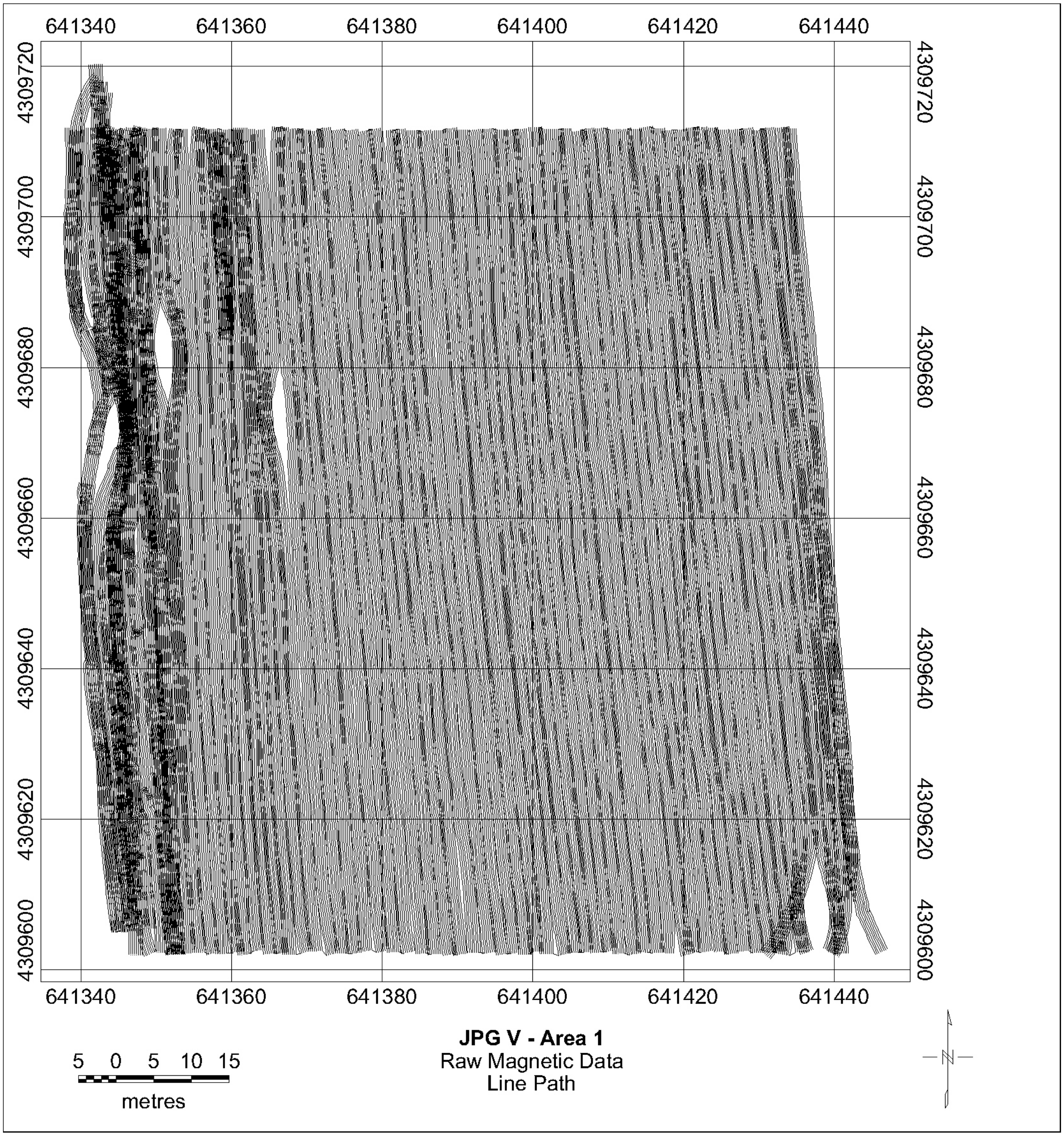

Figure 6. Area 1 from JPG TD – sensor track density.

The data gaps, which are indicated in Figure 6 by holes in the sensor track density, create problems for the matched filter algorithm. The default gridding process used to create the map shown in Figure 7, for example, did not allow the gaps to be interpolated. These data gaps in the gridded data will be enlarged by one-half the size of the filter window[1] during the matched filtering process. As a result, anomalies near the margin of data gaps will be missed if the data gaps are not interpolated during the gridding process.

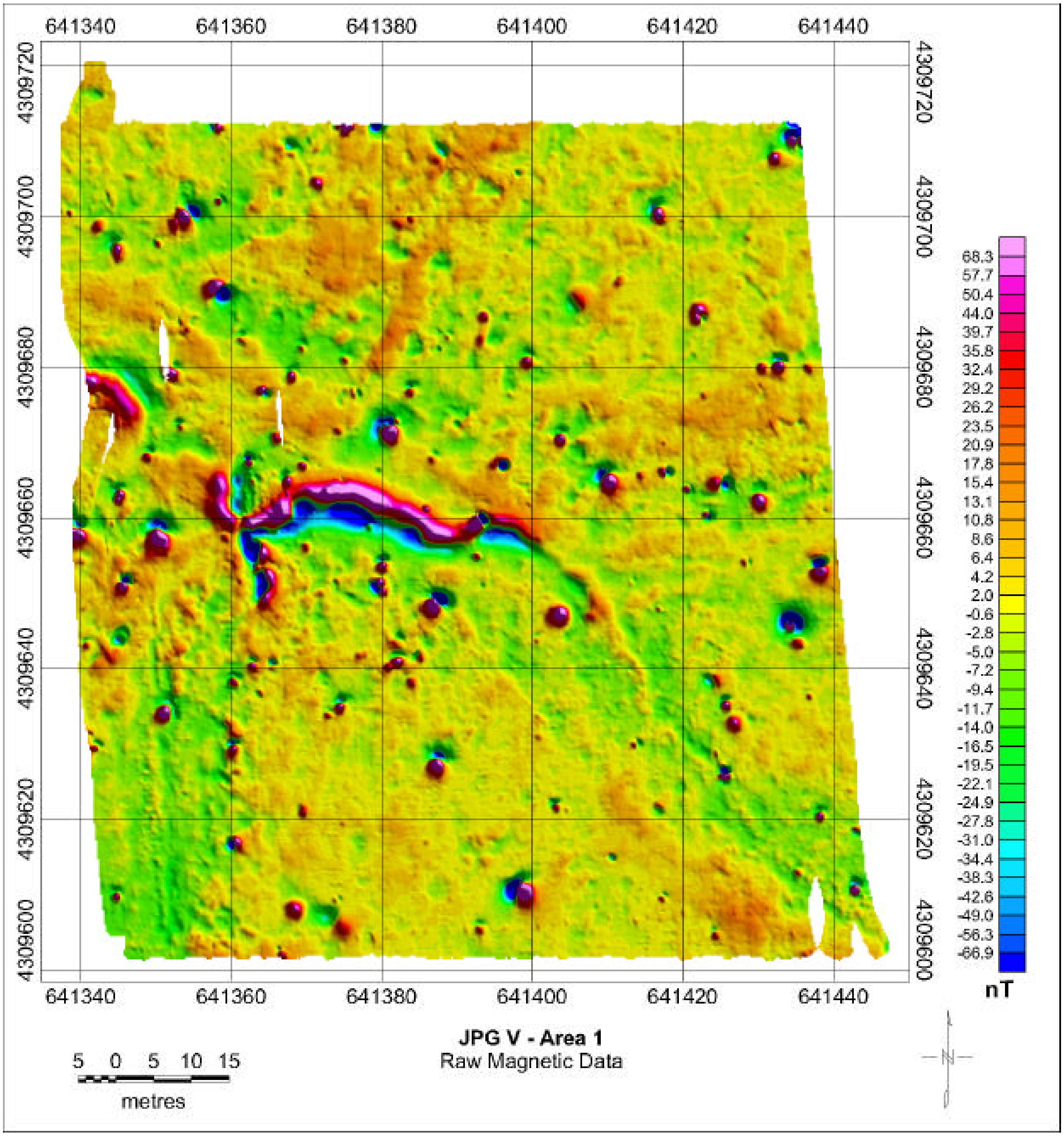

Figure 7. Color-coded map of the *MTADS* magnetic data, Area 1 JPG TD.

By allowing data gaps to be interpolated during the gridding process, the problems associated with data gaps are eliminated. OASIS Montaj allows the user to define the distance over which grid values are interpolated. The built in OASIS Montaj interpolation routines are based on published schemes[3,4]. Figure 8 presents a map of Area 1 with the data gaps filled in (i.e., interpolated) during gridding.

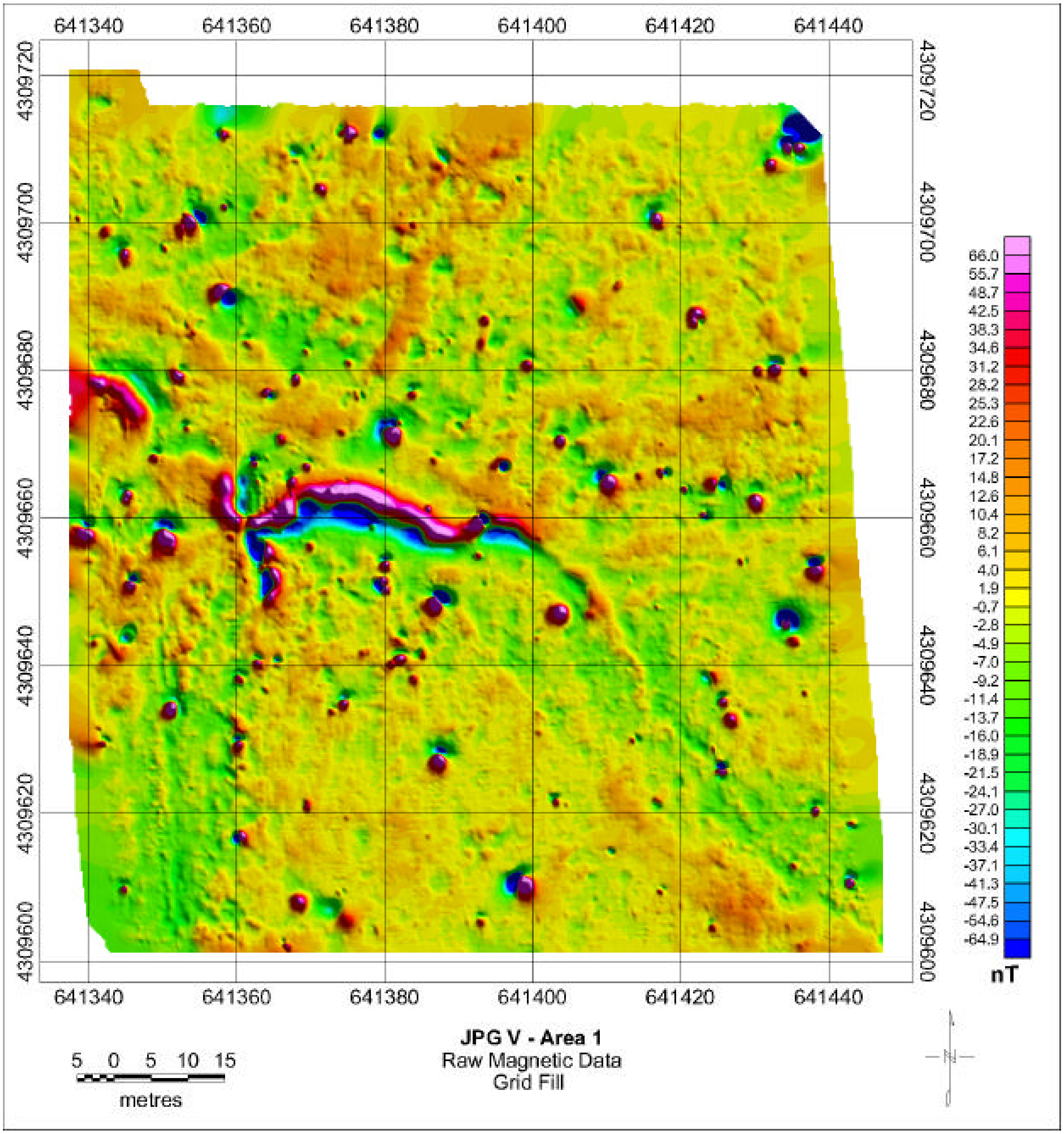

Figure 8. Color-coded map of the *MTADS* magnetic data, Area 1 JPG TD. Note that the data gaps apparent in Figures 6 and 7 have been interpolated.

Figures 9 through 16 present results of the OASIS Montaj matched filter data from Area 1. The various maps are derived from the database that contains the filter output and model parameters that were derived during filtering.

The series of maps and the associated logic presented below differs from the IDL prototyped matched filter procedures. The IDL prototyped matched filter algorithm did not search over multiple depths and did not store the model parameters. Instead, the filter algorithm was repeatedly run at various depths and the derived filter images were each examined for peaks (i.e., anomalies). The anomaly lists were subsequently combined into a master list. Once the master anomaly list was created, the measured data (not the gridded data) around each anomaly location was submitted to a dipole-estimating algorithm. The dipole-estimating algorithm analyzed each target and stored the best fitting model parameters. The anomalies were then screened and sorted based upon the derived model parameters.

The process presented herein basically tries to enhance or retain anomalies that are observed in the raw magnetic data while reducing or eliminating those features that are not associated with expected signatures. All of the model parameters were derived from the gridded approximation of the measured data.

Figure 9 presents the matched filter output of Area 1, JPG, without any post processing. As observed in the figure, a number of anomalies possess very large amplitudes while others do not appear to be caused by an isolated item (i.e., they are not localized and appear to be related to the background geology – compare Figures 8 and 9).

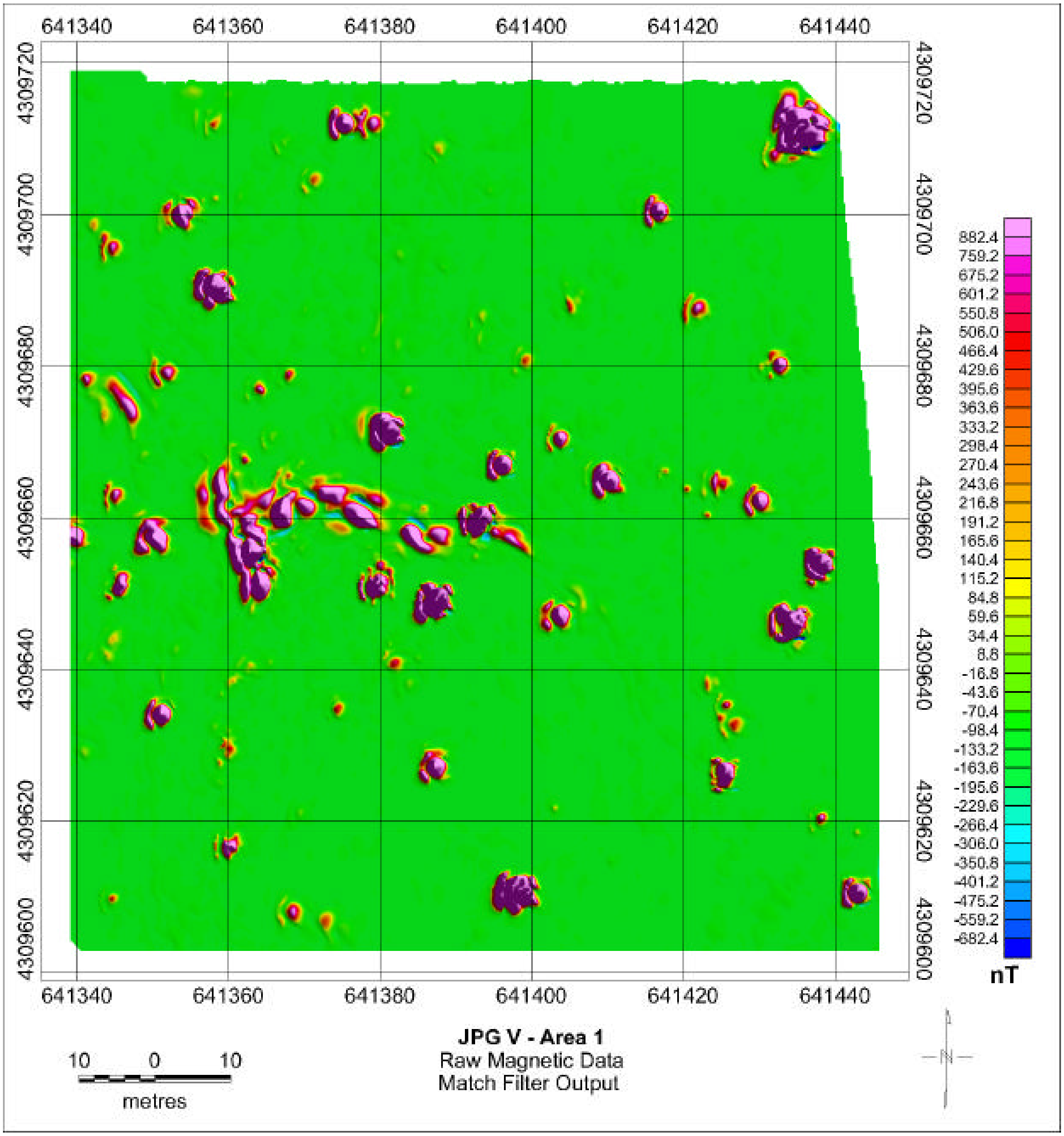

Figure 9. Color-coded map showing the results of the matched filter, Area 1 JPG TD.

Figure 10 presents the ratio of the matched filter output and the derived model error term. This 'ratio' map is notably different in nature than that shown in Figure 9. Unlike the noise-free synthetic data case presented earlier, the presence of complicated structures in the measured response associated with nearby targets, clutter, or geologic sources produces numerous potential targets.

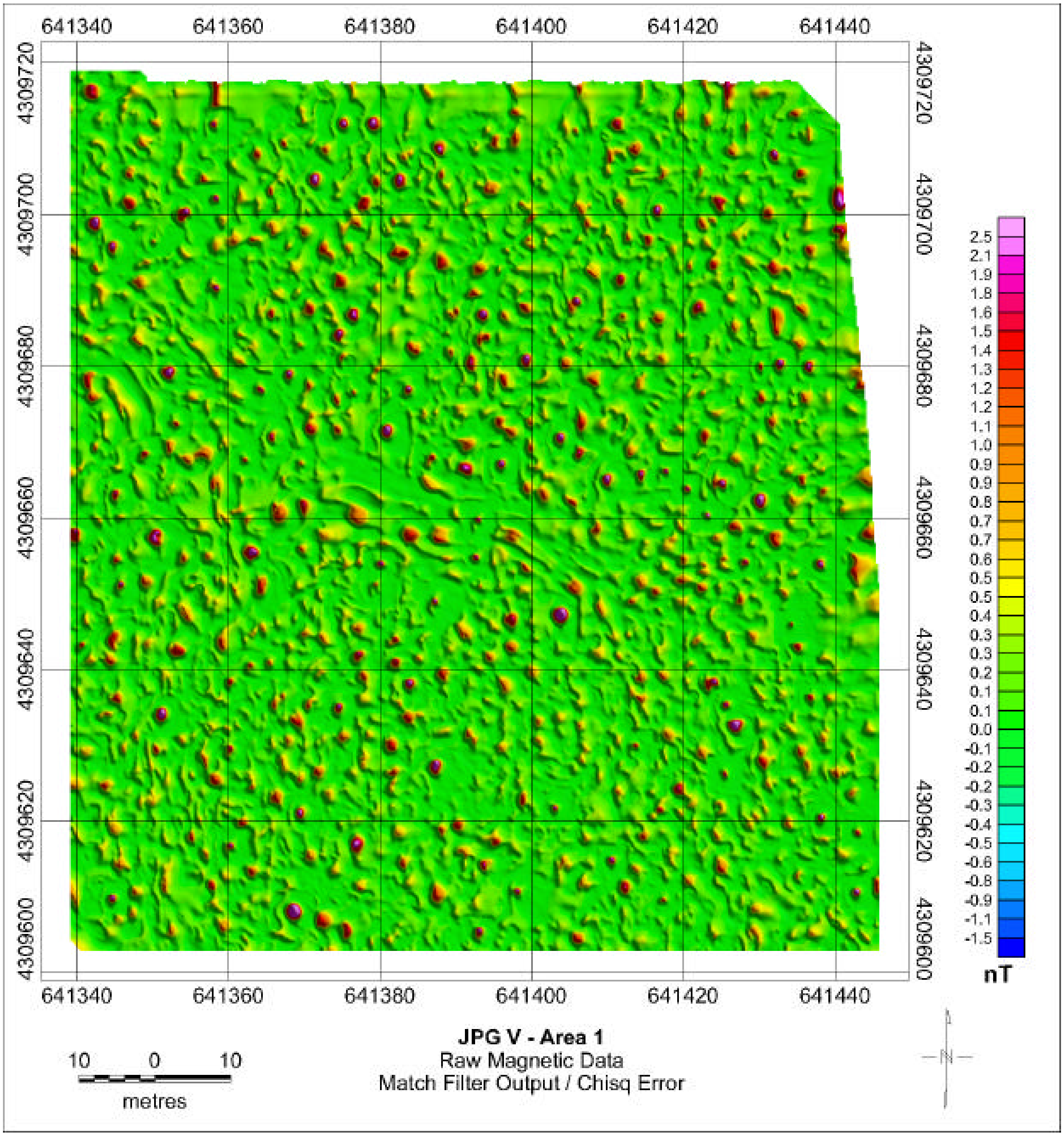

Figure 10. Color-coded map showing the results of dividing the matched filter output by the derived model error; Area 1 JPG TD.

Based on a visual inspection of the filter output and raw data, it was noted that realistic anomalies observed in the raw data also had filter output values larger than five. Figure 11 presents the ratio of the matched filter output and the derived model error term for those filter values that are greater than five. [Note: The output filter values depend on the filter box size – a filter box with a base length of 3.75m was used for this example. It is incorrect to assume that different data sets should apply the same threshold.]

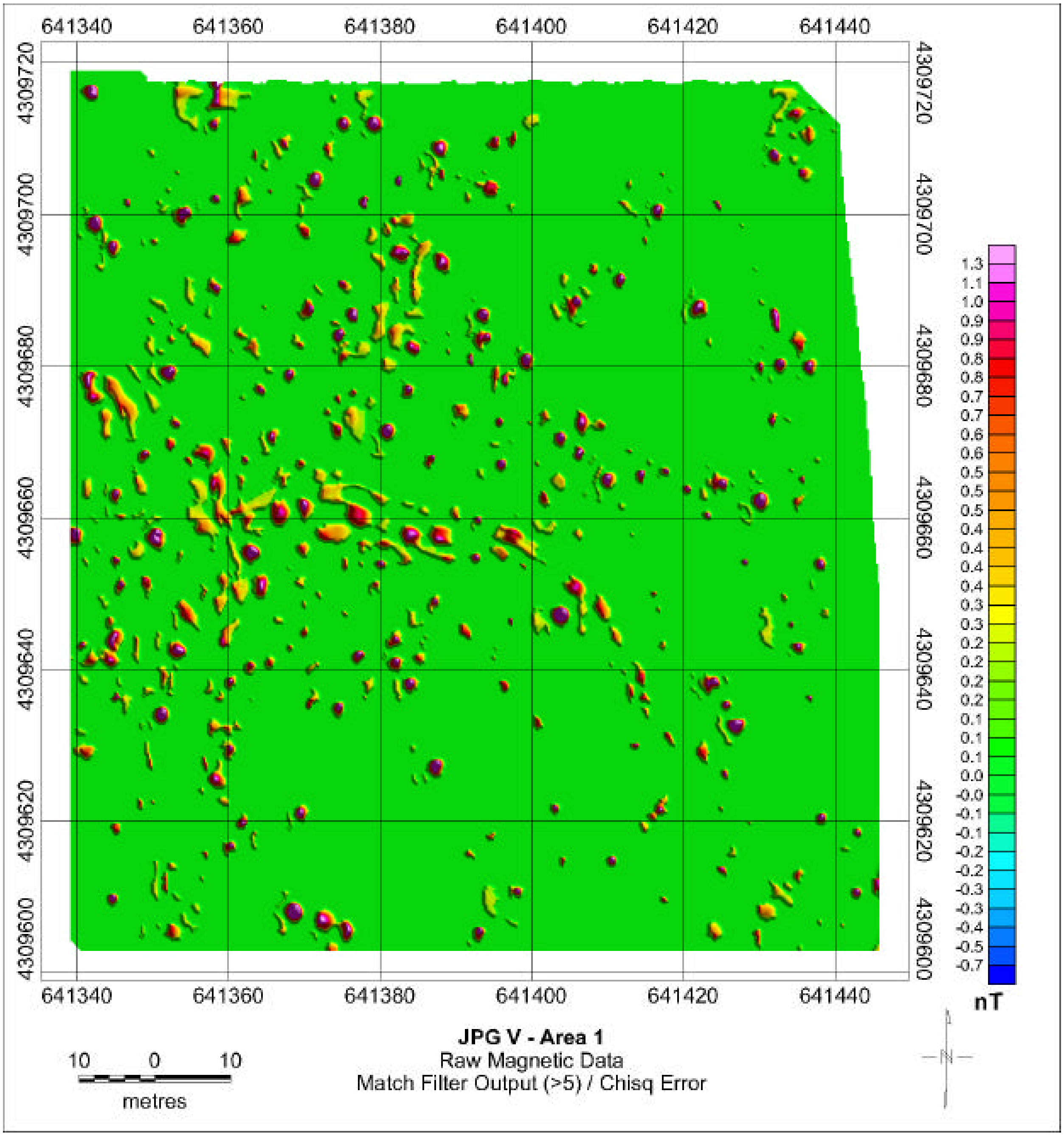

Figure 11. Color-coded map showing the results of dividing the matched filter output values that are larger than five by the derived model error; Area 1 JPG TD.

Discarding those locations that had a reported depth (depth is one of the fitted parameters) of greater than one meter and an apparent size (apparent size is also one of the fitted parameters) of less than 0.13 m further restricted the data presented in Figure 12. These data were then used as the final filter output. Potential anomalies were selected using the OASIS Montaj grid peak utility.

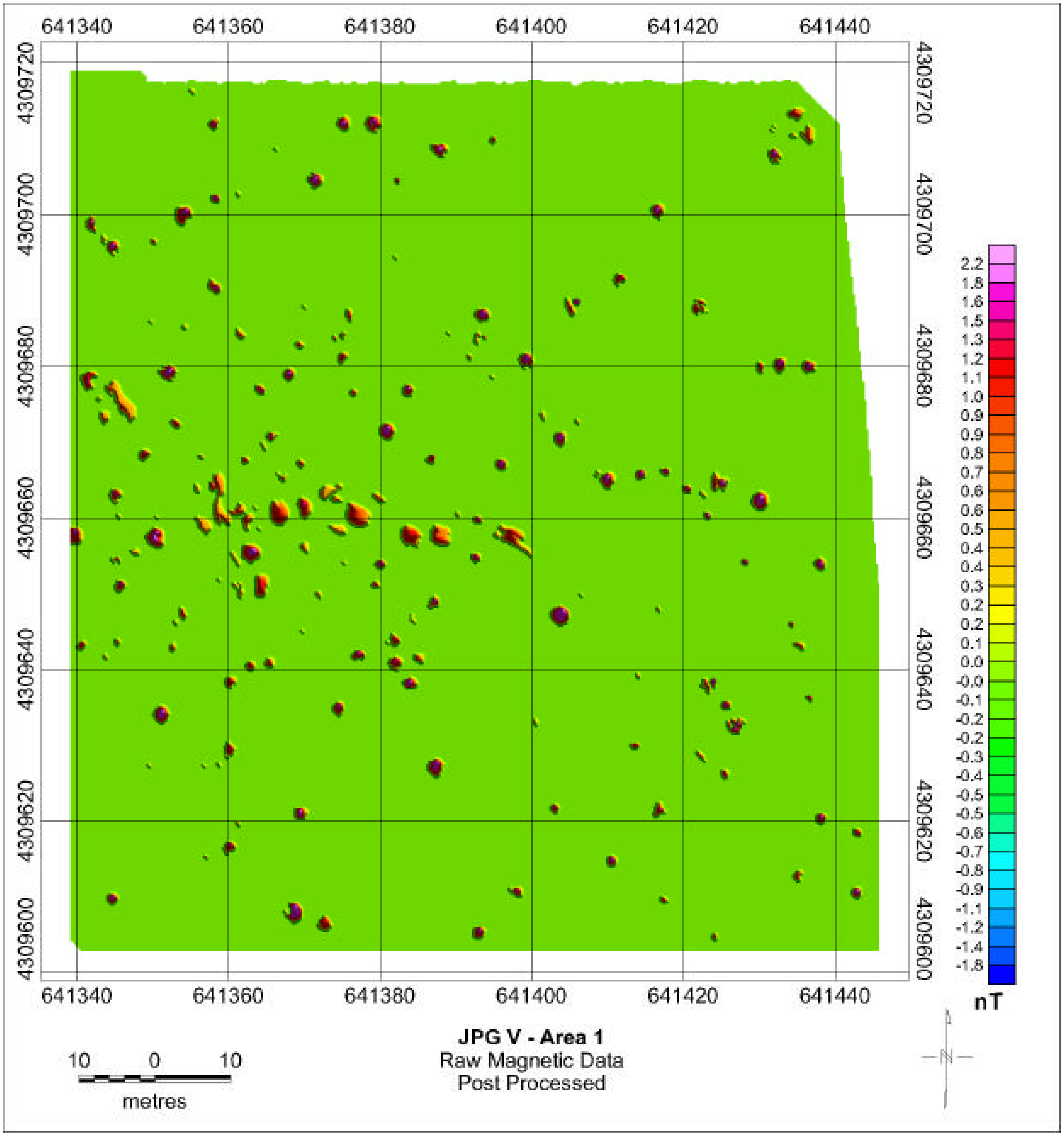

Figure 12. Color-coded map showing the final post-processed results of the matched filter; Area 1 JPG TD. See text for discussion.

Figure 13 presents the final post-processed matched filter output grid overlain by the ground truth (+ symbols and text) and the anomalies selected by the grid peak executable (circles; minimum peak value of 0.3). Utilizing the fitted model parameters to improve the filter output (as described above) revealed 11 targets that are not apparent in the unprocessed filter output (compare Figures 13 and 14). The additional detected targets included 57mm, 60mm, and 81mm items.

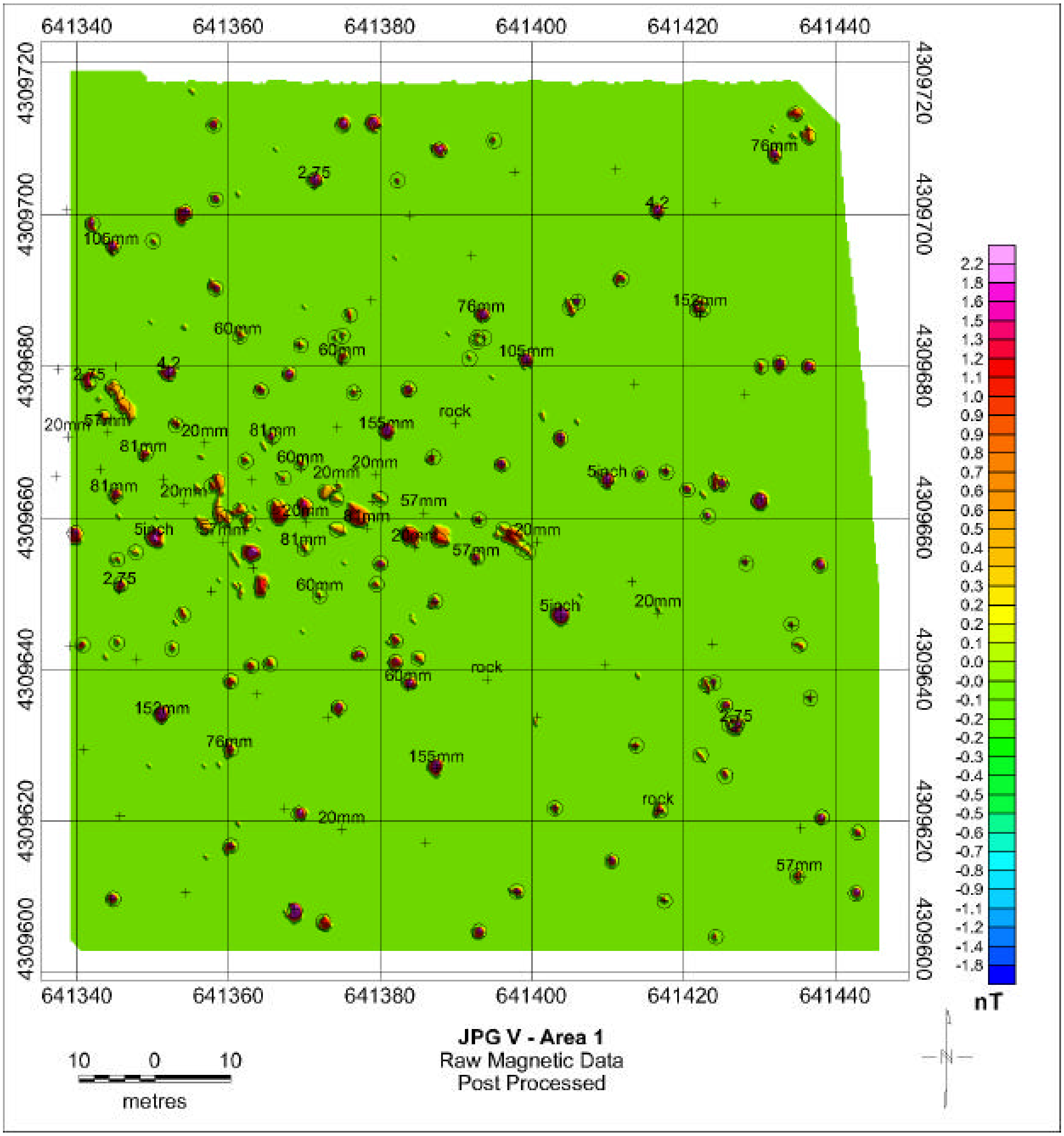

Figure 13. Color-coded map showing the final post-processed results overlain by the ground truth (+) and anomaly picks (circles); Area 1 JPG TD.

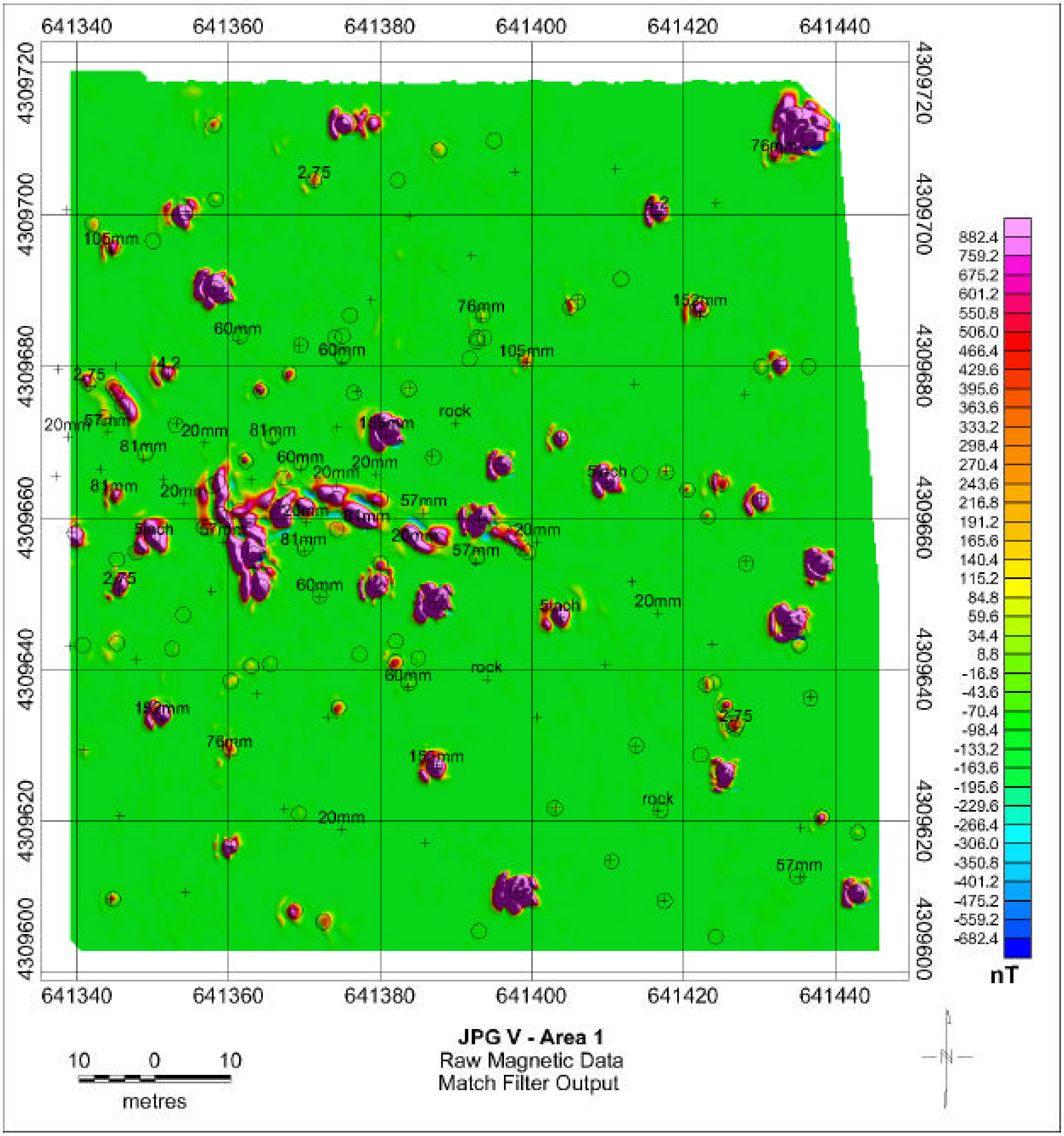

Figure 14. Color-coded map showing the original matched filter output overlain by the ground truth (+ and text) and anomaly picks (circles); Area 1 JPG TD. Comparing these data with that shown in Figure 13 indicates that utilizing the model parameters to post process the filter results identified an additional 11 emplaced targets.

The anomalies identified after screening using the IDL prototyped filter are superimposed (using square symbols) on the final processed OASIS Montaj matched filter results in Figure 15.

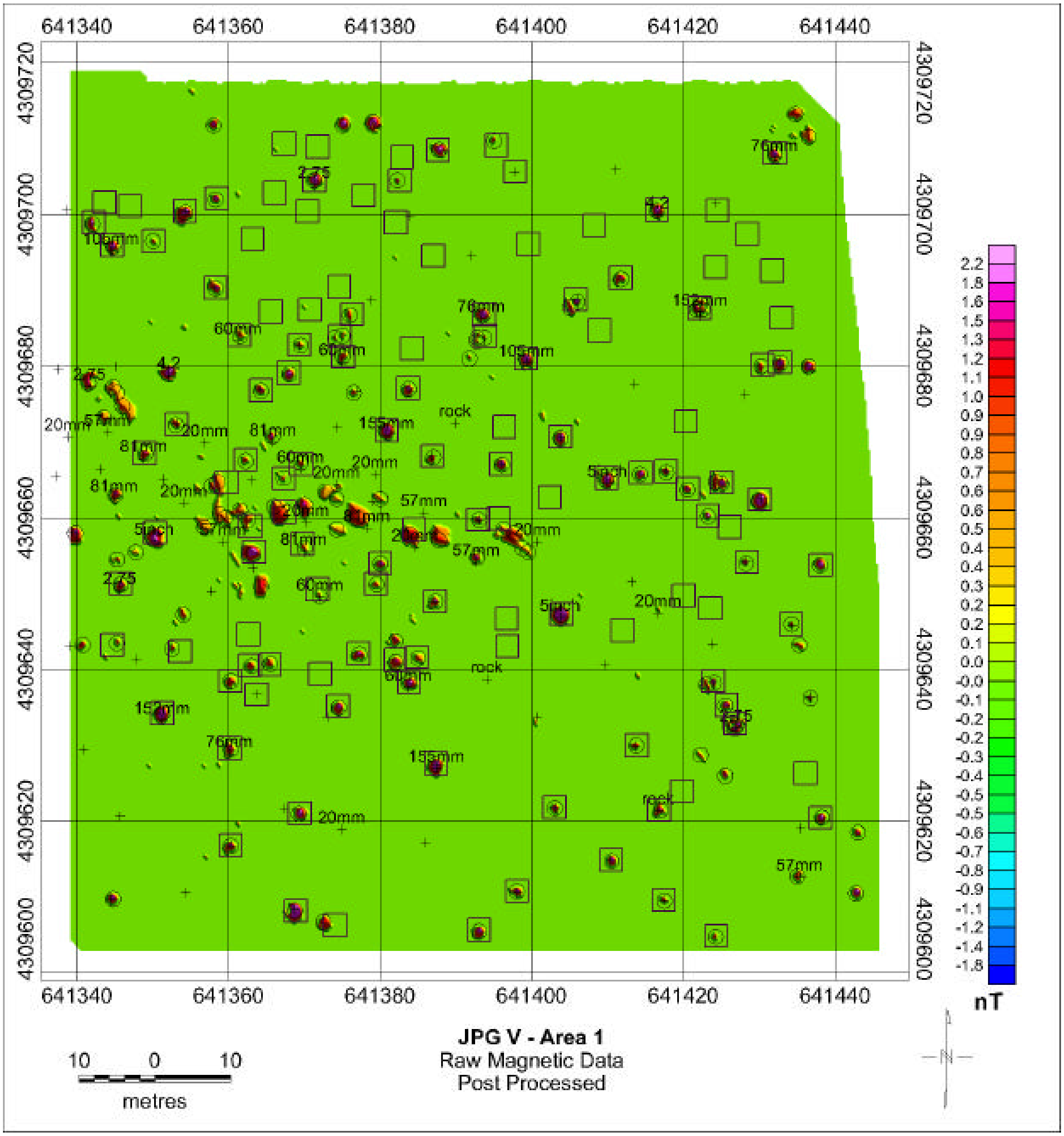

Figure 15. Color-coded map showing the final post-processed results overlain by the ground truth (+), OASIS Montaj matched filter anomaly picks (circles), and anomaly picks (after screening) using the IDL prototyped matched filter algorithm (squares); Area 1 JPG TD.

In summary, a total of 150 anomalies were identified for Area 1 using the OASIS Montaj embedded matched filter. Table 4 presents a comparison of the detected versus emplaced UXO items in Area 1.

Table 4. Detected versus Emplaced UXO items in Area 1, JPG TD

Ordnance Type	Number Identified	Emplaced
20mm	0	10
57mm	2	5
60mm	5	5
76mm	3	3
81mm	4	5
105mm	2	2
152mm	2	2
155mm	2	2
4.2 inch	2	2
5 inch	3	3
2.75 inch	4	4
Total	**29**	**43**

For these data, the detection rate was 67% primarily because, as noted in Table 4, none of the 20mm items produced peak values above the selected threshold of 0.3. This is not unexpected based on our previous experience with the IDL prototyped matched filter and the almost negligible measured response associated with the 20mm's (Figure 16). If the 20mm items are excluded, the detection rate increases to 88%. The three missed 57mm items were located near magnetically active regions and probably would not be detected visually (Figure 16). The missed 81mm item was also located within an active magnetic area and is not readily apparent when the raw magnetic data are inspected visually (Figure 16).

The percentage of items declared as potential targets by the matched filter algorithm that are not emplaced ordnance items is approximately 80%. This is similar to number of false alarms reported during the previous IDL development[1].

Figure 16 presents the raw magnetic data overlain by the identified anomalies from the OASIS Montaj embedded routine (circles) and the ground truth (+ symbol and text). Although some of the matched filter target selections would probably be discarded after visually inspection, we did not do so to preserve this evaluation of the filtering approach.

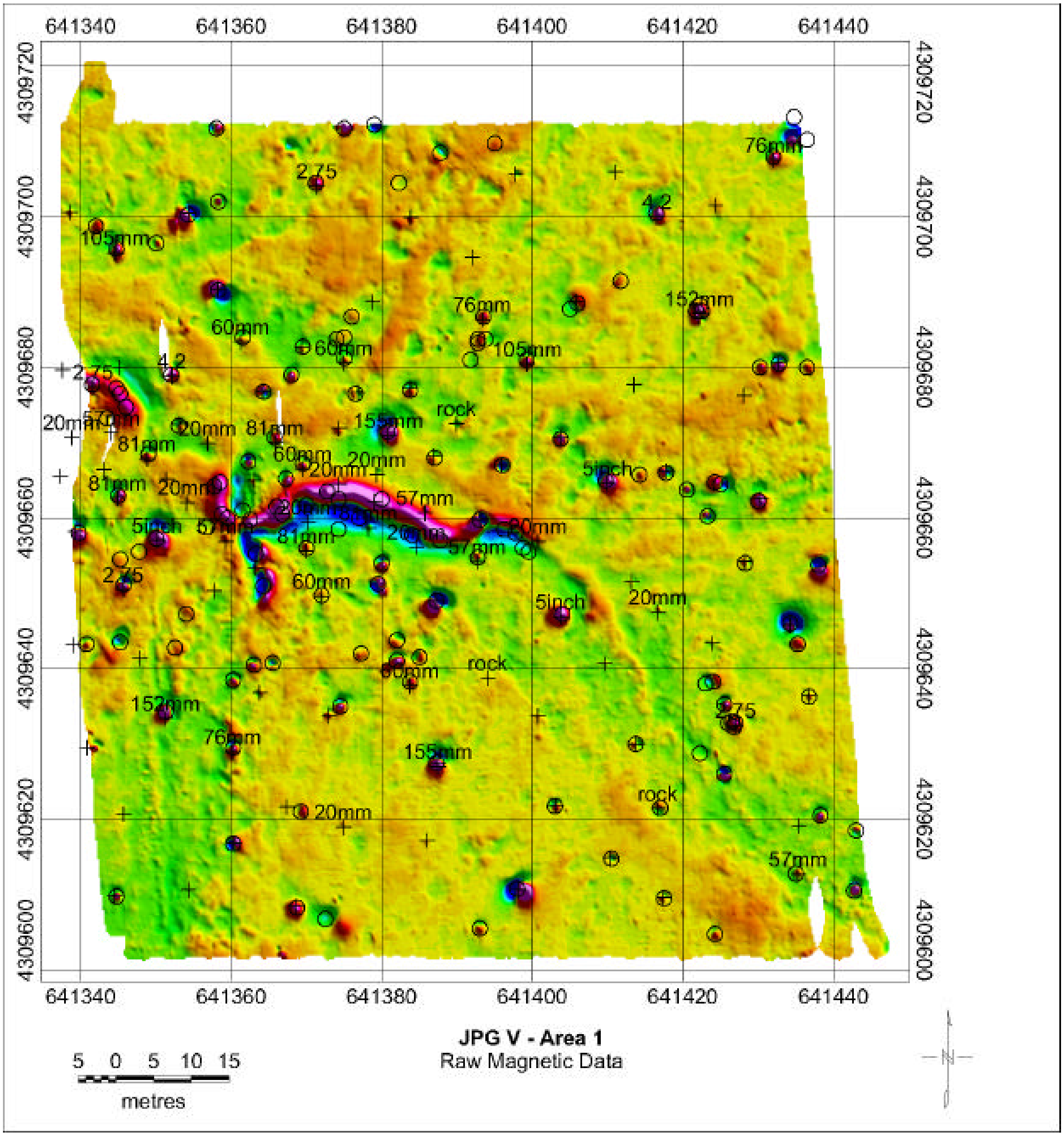

Figure 16. Color-coded map showing the raw magnetic data overlain by the ground truth (+) and anomalies identified by the OASIS Montaj embedded matched filter routine (circles); Area 1 JPG TD.

5.2 Data Assessment

The magnetometer array data used for the OASIS Montaj embedded matched filter demonstration was, in general, excellent and the seeded UXO covered a good range of sizes and types.

5.3 Technology Comparison

The OASIS Montaj-embedded matched filter appears to do a reasonable job of isolating potential targets in the magnetically noisy and active areas encountered in JPG TD. This was in agreement with the results of our previous tests using the IDL prototyped matched filter[1]. Results from the synthetic and JPG magnetic data affirm that the OASIS Montaj matched filter functions as anticipated.

The analytic signal, which is defined as the sum of the squares of the derivatives in the x, y, and z directions, is sometimes used to locate the edges of magnetic source bodies, particularly where remanence and/or low magnetic latitude complicates interpretation. As shown in Figure 17, the anomalies identified using the OASIS Montaj matched filter correlate well with peaks in the Area 1 analytic signal magnetic data.

5.4 Time and Experience Assessment

Approximately forty minutes were required to run the matched filter routine on the JPG Area 1 magnetic data. By comparison, the IDL prototyped code required 15 to 80 minutes of operating time for each selected depth of investigation[1]. Five to 12 separate depths were used to create the master anomaly lists (before screening) during the demonstration of the IDL prototyped matched filter algorithm[1].

5.5 Technology Transition

The technology of the matched filter addresses concerns raised by the Report of the Defense Science Board Task Force on Unexploded Ordnance (UXO) Clearance and related programs[5]. This phase of the program transitioned the prototyped IDL code into a commercially available geophysical data processing environment.

The matched filter dynamic link library and associated Geosoft executable are archived on the attached CDROM.

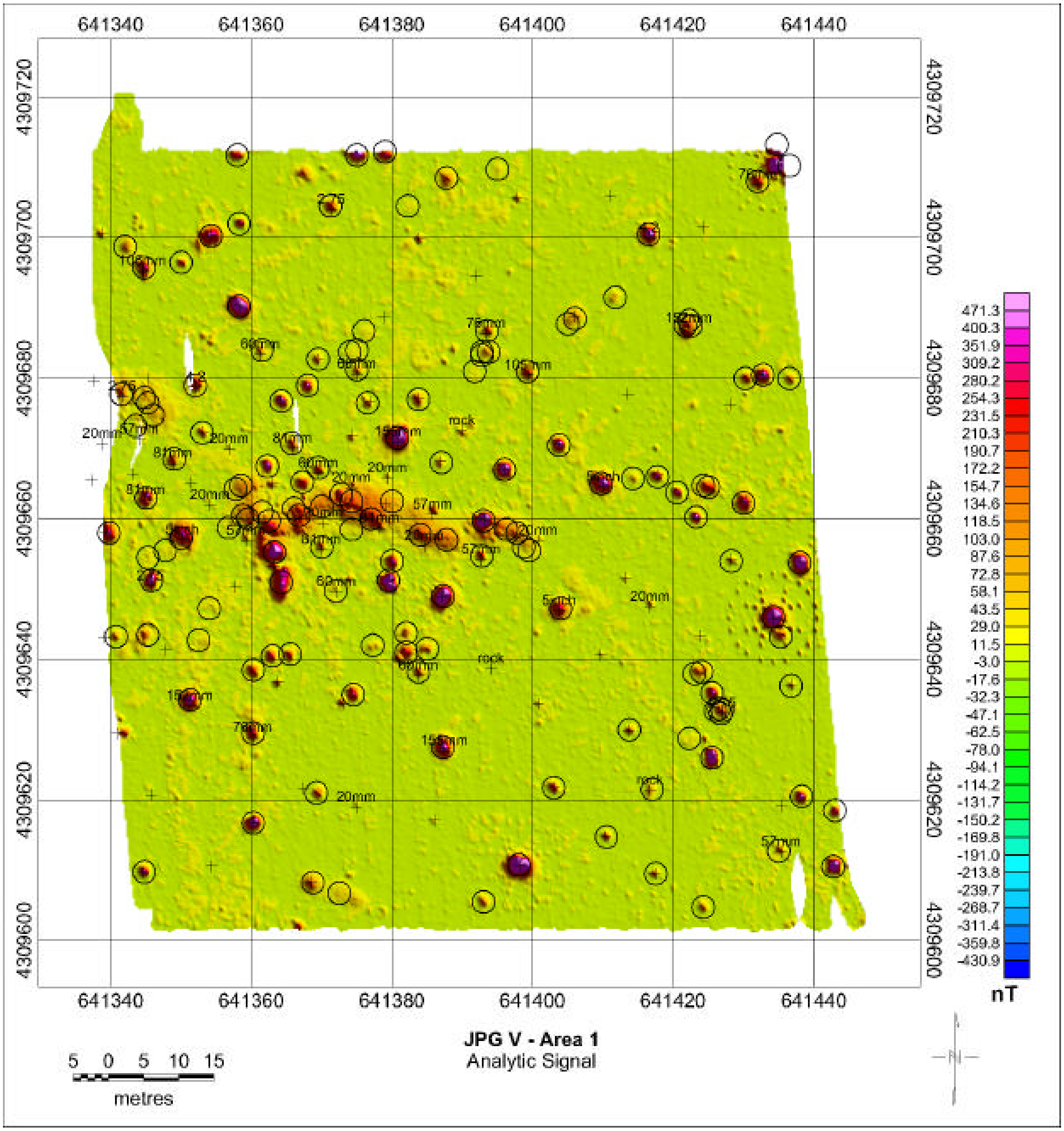

Figure 17. Color-coded map showing the calculated analytic signal overlain by the ground truth (+ and text) and anomalies identified by the OASIS Montaj embedded matched filter routine (circles); Area 1 JPG TD.

6.0 Lessons Learned

1. The size of the user-selected filter box affects the speed and accuracy of the matched filter results. As used here, the term 'filter box' refers to an area around each grid node. Data points that are within the filter box are submitted to the regression routines (note that the term filter box does not refer to a volume, but rather to an area). The center of the filter box is systematically moved to each grid point. The ideal size of the filter box for a given anomaly encompasses the target's response (i.e., has an appropriate spatial footprint) but does not include extraneous noise. Items that are large and deep have larger spatial signatures than smaller items and therefore require a larger filter box. Items that are small and shallow possess smaller spatial footprints and therefore require a smaller filter box. If a non-optimal filter box is selected, the regression algorithm returns non-optimal fit results. Note that using a single filter box size for sites with multiple UXO types and expected burial depths cannot be optimal for all anomalies. In fact, assuming that the optimal filter box is rectangular (as is done here) is problematic at best. Because of this, the *MTADS* Data Analysis System requires manual editing while selecting the filter box size and shape for each anomaly (rectangle areas are not assumed; instead, polygons are used). Manual intervention, however, is not desired for automatic processing techniques. Future efforts to improve the matched filter results should add procedures to change the size and shape of the filter box to maximize signal content at the center of the filter box while minimizing noise.

2. The application of the matched filter process, as described and implemented here, requires user intervention and insight. Because the anticipated UXO response is dipolar, using a dipole-based matched filter is attractive. The problems associated with noise and filter box-size, however, require that the effects of each processing step be reviewed.

3. Processing artifacts generated during filtering degrade the filter output. The artifacts are most notable when the filter box contains a portion of a strong dipolar signature. In other words, the artifacts are most pronounced when the interrogation point (a grid value) is near - but does not encompass - a magnetic dipole. This produces 'ringing' artifacts around strong dipoles. Future work should identify this phenomenon during filtering and reduce its effects.

4. Recent experience analyzing magnetic data from large sites, as is the case with vehicular or airborne towed arrays, strengthens the desire for and necessity of automatic and systematic anomaly picking algorithms. Continuing the development of this technology by analyzing existing, large datasets to gain a better understanding of the issues involved at sites with diverse UXO types and different noise characteristics is recommended.

7.0 References

1. Bell, T., Jones, R., Soukup, J., and Puc, B., “Matched Filter Processor for Detection and Discrimination of Unexploded Ordnance”, ESTCP Final Report for project 199918, AETC Report VA-095-050-TR-01, November 26, 2001.

2. "Navy Tri-Service Environmental Quality Research Development, Test and Evaluation Strategic Plan," October 1994, p. Cleanup-21

3. Briggs, I., “Machine contouring using Minimum Curvature”, Geophysics, v. 39, No. 1, p. 39-48, 1974.

4. Swain, C., “A Fortran IV Program for interpolating irregularly spaced data using the difference equations for minimum curvature”, Computer & Geosciences, v. 1, p. 231-240, 1976.

5. Office of the Undersecretary of Defense (Acquisition and Technology), "Report of the Defense Science Board Task Force on Unexploded Ordnance (UXO) Clearance, Active Range Clearance, and Explosive Ordnance Disposal (EOD) Programs, April 1998.

Appendix A. Points of Contact

Jeffrey Marqusee	ESTCP Director Tel: (703) 696-2120 Fax: (703) 696-2114 Email: marqusj@acq.osd.mil
George Robitaille	DoD Project Officer Army Environmental Center SFIM-AEC-ETD Aberdeen Proving Ground, MD 21010-5401 Phone: (410) 436-6865 Fax: (410) 436-6836 Email: gerobita@aec.apgea.army.mil
Dean Keiswetter	Investigator AETC Inc. 3711 Junction Blvd Raleigh, NC 67603 Phone: (919) 661-5529 Fax: (919) 661-5530 Email: dkeiswetter@nc.aetc.com